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Research Article

First insights into the scale of invasions in African marine protected areas: leveraging global databases and citizen science data

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Abstract

Up-to-date information on the distribution of alien species is essential for evidence-based management. However, routine monitoring is resource intensive. This has led to regional biases in the availability of information on invasions, with little understanding of invasions in many developing regions, including Africa. This knowledge gap, particularly problematic for marine protected areas (MPAs), challenges the ability of African states to meet their obligations under the Global Biodiversity Framework (GBF) Target 6. This study drew on freely available global databases (Protected Planet; World Register of Introduced Marine Species; World Register of Marine Species) and citizen science data (iNaturalist) to provide novel insights into marine alien species in African MPAs. A total of 27 species were recorded within 17 MPAs across seven countries. The potential threat posed to these MPAs was assessed using the EICAT and SEICAT impact schemes. Worryingly, species known to have impacts of massive or major magnitude were documented in nine MPAs (Table Mountain National Park, Robben Island, Sixteen Mile Beach, Langebaan Lagoon, Namaqua National Park – all in South Africa); Namibian Islands (Namibia); Ilhas Formosa, Nago and Tchedia (Urok) (Guinea-Bissau); Banc d'Arguin National Park (Mauritania); Massa (Morocco)). When used in conjunction with curated databases, iNaturalist offered cost-effective and verifiable records of some alien species in under-surveyed MPAs. By leveraging data from disparate databases, this study improves our knowledge of the scale of invasions in African MPAs and provides a foundation upon which States can prioritise monitoring within their MPA networks. Ultimately, these data could support the development of targeted routine monitoring programmes which could assist the management of marine invasions and the attainment of GBF Target 6.

Key words: Africa, biological invasions, community science, data acquisition, impacts, iNaturalist, management, protected areas

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Introduction

Biological invasions are a major driver of global environmental change (Ricciardi et al. 2021) and protected areas are not immune to the impacts of invasive alien species (Shackleton et al. 2019, 2020). The Kunming-Montreal Global Biodiversity Framework (GBF), developed under the Convention on Biological Diversity (CBD), proposes 23 targets to support and guide the achievement of the Sustainable Development Goals and the global vision to reduce anthropogenic impacts on biodiversity by 2030 (Robinson et al. 2025). Target 6 aims to reduce the rate of introductions and establishment of known or potentially invasive alien species by at least 50% by 2030 (CBD/COP/DEC/15/4). The aim of this target is to eliminate,

minimise, reduce and mitigate the overall impacts of alien species on biodiversity and ecosystem services (CBD/COP/DEC/15/5). The target also requires the eradication or control of alien species in priority sites (e.g. protected areas) as these areas allow for conservation objectives to be met while providing economic, political and social benefits (Busch 2008).

Although the availability of global data on alien species and their distribution has improved greatly over the last few decades (Pyšek et al. 2020), substantial geographical biases still remain, often reflecting the developmental and socioeconomical status of regions (Pyšek et al. 2008, 2020; Nuñez and Pauchard 2010). This can be seen, for example, in the focus of research effort in the Americas and Europe (Hulme et al. 2014). Inconsistencies in the availability of information across continents has also been highlighted. For example, as of 2006, work in South Africa accounted for approximately two-thirds of research effort on biological invasions on the African continent (Pyšek et al. 2008). Dedicated efforts to provide up-to-date alien species lists (e.g. Zengeya and Wilson (2023) for South Africa)) has improved the understanding of alien species in some countries, but many still lag behind. For example, there is a need for comprehensive invasive plant species lists for sub-Saharan Africa (Witt et al. 2018) and no data are available for many regions (Richardson et al. 2022). The same situation exists for other taxa. While the responsibility for the provision of such information usually falls on to researchers, the outputs of such studies are of practical use for managers (Ojaveer et al. 2015). The lack of foundational knowledge within understudied regions has the potential to perpetuate knowledge debt. This challenge is especially prevalent in developing regions where the management of alien taxa is already limited (Kumar Rai and Singh 2020).

Global declines in marine biodiversity and threats posed by anthropogenic actions have led to the increasing implementation of marine protected areas (MPAs) (Ban et al. 2015; Chukwuka et al. 2025). Defined as geographical spaces dedicated to legally manage long-term conservation of ecosystem functions, services and cultural values (Day et al. 2012), MPAs are important marine conservation tools. Given the multitude of threats (including biological invasions) facing marine systems (Evariste et al. 2018; Horwitz et al. 2020; Pyšek et al. 2020; Renchen et al. 2021) and the fact that conservation agencies have limited resources (Delaney et al. 2008; Beric and MacIsaac 2015), managers must prioritise how and where to spend scarce resources. However, despite much effort, current management and conservation efforts are inadequate in most protected areas (Crain et al. 2009; Borja et al. 2016; Chukwuka et al. 2025). Marine protected areas serve a number of economic, ecological and societal aims, all of which are undermined by biological invasions. The need to address alien species and quantify the scale of invasions in MPAs is thus crucial to ensure that MPAs meet their intended purpose.

Monitoring provides critical information on the changing scale of invasions and is crucial for evidence-based management (Lehtiniemi et al. 2020; Loureiro et al. 2021). When collected systematically over space and time, such information supports comprehensive databases that provide temporal and spatial insights into invasions (Delaney et al. 2008). However, monitoring is challenging in marine environments because of to their complex nature (D'Amen and Azzurro 2020). Their underwater landscapes and interconnectedness make invasions in the marine realm difficult to document and manage (Arndt et al. 2018). Additionally, large-scale, long-term monitoring rarely occurs due to resource limitations (Delaney et

al. 2008; Beric and MacIsaac 2015). Cost-effective methods of monitoring are needed to bridge the gap between data requirements and scientific understanding (Lehtiniemi et al. 2020; Howard et al. 2022). One way of achieving this is to utilise crowd-sourced data provided by citizen science initiatives (Horwitz et al. 2020; Howard et al. 2022). The advancement of technology and the recent proliferation of online platforms has enhanced the potential for monitoring by using devices and smartphone applications (Daniels et al. 2022; Howard et al. 2022). Applications, such as iNaturalist, enable observers to upload photographic evidence of individual sightings and suggest taxonomic identifications (Pimm et al. 2015; Howard et al. 2022). Records collected by observers have the potential to provide a large volume of data over a wide area. If utilised with due attention to inherent limitations, citizen science offers a complementary source of data to support effective monitoring of alien species (Howard et al. 2022; Potgieter et al. 2024). iNaturalist has facilitated many useful insights within the marine realm, including improved understanding of reef fish species richness (Roberts et al. 2022), biodiversity patterns (Rocha et al. 2024) and invasions (Compagnone et al. 2024).

For African countries to meet their obligations under GBF Target 6, better foundational knowledge on the presence of alien species within MPAs is essential. Underdeveloped regions are already experiencing a high economic burden which is exacerbated by the financial demands associated with managing invasive species (Bradshaw et al. 2024). The monitoring required to provide information for routine management of alien species has the potential to further intensify financial strain, challenging the acquisition of foundational knowledge and the implementation of effective management. Accordingly, this study aimed to: (1) provide insights into the scale of alien species in African MPAs through the use of global databases and citizen science data from iNaturalist; and (2) assess the potential environmental and socio-economic impacts posed by these taxa.

Methods

Marine protected areas (MPAs) along the African coast were identified using the open-access Protected Planet database (https://www.protectedplanet.net/en/thematic-areas/marine-protected-areas; accessed: 9 January 2024). This database, the most comprehensive and up-to-date source of data on protected areas, collates submissions from government agencies, non-governmental organisations and local communities. Marine Protected Areas were defined using the filters listed in Suppl. material 1. Data, extracted over a single day (9 January 2024), covered all African MPAs declared prior to January 2024.

Records of all species reported as alien [i.e. species whose presence in a region is attributable to human actions enabling crossing of biogeographical barriers *sensu* Richardson et al. (2011)] along the African coast were extracted from the World Register of Introduced Marine Species (WRiMS; Costello et al. (2024); https://www.marinespecies.org/introduced/aphia.php?p=checklist; accessed: 10 September 2024). Data included both occurrence records of alien species as well as records of established populations. This database was selected as it collates data from peer-reviewed articles to provide the most comprehensive and standardised global-scale database of marine introduced organisms (Costello et al. 2021). All species records that were extracted were inspected and a three-step cleaning procedure was applied. As data extracted from WRiMS include both accepted names and

synonyms with no option to filter out these redundancies, all taxonomic duplicates were checked and removed to avoid overestimations of the number of alien species. Scientific names were then updated according to the most recent nomenclature collated in the World Register of Marine Species (WoRMS; Ahyong et al. (2024); https://www.marinespecies.org; accessed: 10 September 2024). Since WRiMS contains both marine and estuarine data, all oligohaline species were inspected. Using current literature to investigate salinity tolerances, only species with a tolerance for marine environments were retained.

To ensure that no published records of alien species were inadvertently excluded, a search was conducted on the ISI Web of Science on 10 September 2024. A systematic literature review was conducted using the following search string "marine" AND "alien" OR "invasive" OR "introduced" OR "nonnative" AND "country name". As the terminology used to describe alien species is inconsistent and highly variable in the literature (Lockwood et al. 2013), broad search terms (i.e. "alien", "invasive", "nonnative" and "introduced") were used to capture as much of the relevant literature as possible. As no additional records of marine alien species were detected in the literature search, the dataset extracted from WRiMS was accepted as complete.

Utilising the explore page on iNaturalist (https://www.inaturalist.org; accessed: 18–19 September 2024), searches were made for each species listed as alien in any African country on WRiMS. Records for each species across all quality grades were extracted from iNaturalist for the period 1 April 2008 (the date of establishment of the iNaturalist platform) to 18 September 2024. Information on the species identification (scientific name and associated media), the date of observation, the date in which the observation was uploaded to the platform, the coordinates of the observations and positional accuracy were extracted for each observation. As some species may have a native range in one African country, but be alien in another, the native range of each species was confirmed using the World Register of Marine Species (WoRMS; Ahyong et al. (2024); https://www.marinespecies.org; accessed 20–21 September 2024) and published articles. To interrogate the geographic distribution of iNaturalist observations and ensure that the observations were, in fact, observed within an MPA, the coordinates for each observation were plotted using the Quantum Geographic Information System (QGIS; version 3.22 LTR). Each observation was plotted on to a map of Africa with the MPAs demarcated [MPA shapefiles from Protected Planet (https://www.protectedplanet.net/en/thematic-areas/marine-protected-areas; accessed: 9 January 2024]). All points were visually inspected and any records from outside MPAs were excluded from further analysis. iNaturalist observations occurring within the native range of a species were also excluded.

To address uncertainty in iNaturalist data and improve its accuracy and reliability, confidence for each observation was scored following the protocol proposed by Ackland et al. (2024). This process included three steps: assessing the species, the image and geolocation of each record. Only records receiving medium or high confidence scores were retained for further analysis. A Kendall's rank correlation was used to assess the relationship between the number of records of alien species as detected in African MPAs through time. Effort was quantified as the number of marine alien species records per 100 records within African MPAs. All statistical analyses were conducted in the R statistical environment (version 4.3.2 – "Eye Holes", R Core Team (2023)).

To determine the threat that these species may pose to MPAs, a literature review was carried out using ISI Web of Science to identify all previously published reports of impact for each species at any global location. The search string "scientific name" AND "impact*" OR "effect*", was applied along with each species name and all previous synonyms. Searches were completed between 25 and 27 September 2024. Environmental impact was categorised according to the mechanisms through which they manifest [i.e. (1) competition; (2) predation; (3) hybridisation; (4) disease transmission; (5) parasitism; (6) poisoning/toxicity; (7) bio-fouling; (8) grazing/herbivory/browsing; (9) chemical; (10) physical or (11) structural impact on an ecosystem; and (12) interaction with other alien species] using the Environmental Impact Classification for Alien Taxa scheme (EICAT; Blackburn et al. (2014)). Socio-economic impacts were classified according to the constituents of human well-being they affect [i.e. (1) safety; (2) material and immaterial assets; (3) health; and (4) social, spiritual and cultural relations] using the Socio-economic Impact Classification for Alien Taxa scheme (SEICAT; Bacher et al. (2017)). Lastly, the magnitude of impact (i.e. massive, major, moderate, minor, minimal or data deficient) reported previously in literature was assigned for each species. Classification of magnitude was based on the maximum impact noted for the species, regardless of location, following Kumschick et al. (2017).

Results

Seventy-nine African marine protected areas (MPAs) were identified across 14 countries (Fig. 1, Suppl. material 2: table S2). A total of 497 marine species were reported as alien in coastal African countries (Suppl. material 2: table S3) on the World Register of Introduced Species (WRiMS), with a total of 440 iNaturalist records for 34 of those species reported from within African MPAs. After excluding records that were not scorable and those with low confidence scores, 307 records (70%) of 27 species were retained for further analysis (Table 1, Suppl. material 2: table S4). Over two-thirds of these observations [211 records (72%)] received a maximum score for image clarity. Examples of such records are provided in Fig. 2.

Of the 27 species recorded on iNaturalist, four were observed within countries with no previous records according to WRiMS. These species included the barnacle *Balanus trigonus* (Mauritania), the bryozoan *Amathia verticillata* (Mauritania and South Africa), the colonial tunicate *Symplegma brakenhielmi* (Senegal) and the crab *Callinectes sapidus* (Guinea-Bissau and Mauritania).

A general trend of increased engagement on iNaturalist was observed, with records of marine alien species in African MPAs increasing significantly over time (Kendall's rank correlation: $\tau = 0.51$, $p < 0.05$; Fig. 3). Records were spread across 17 MPAs from seven countries (Fig. 4). Two MPAs accounted for 85.7% of all records (i.e. Table Mountain National Park MPA (South Africa) and Banc d'Arguin National Park (Mauritania)], with many other MPAs having fewer than five records. Table Mountain National Park MPA had the most records of alien taxa [i.e. 241 records (78.5%)] and the highest number of species detected on iNaturalist (15 species). The MPA with the second highest number of records was Banc d'Arguin National Park in Mauritania (22 records; 7.2%), the second highest number of species (8 species) was also detected in this MPA.

Of the 27 alien species detected in African MPAs, environmental impact had been reported for 23 species and socio-economic impact for 14 species (Suppl.

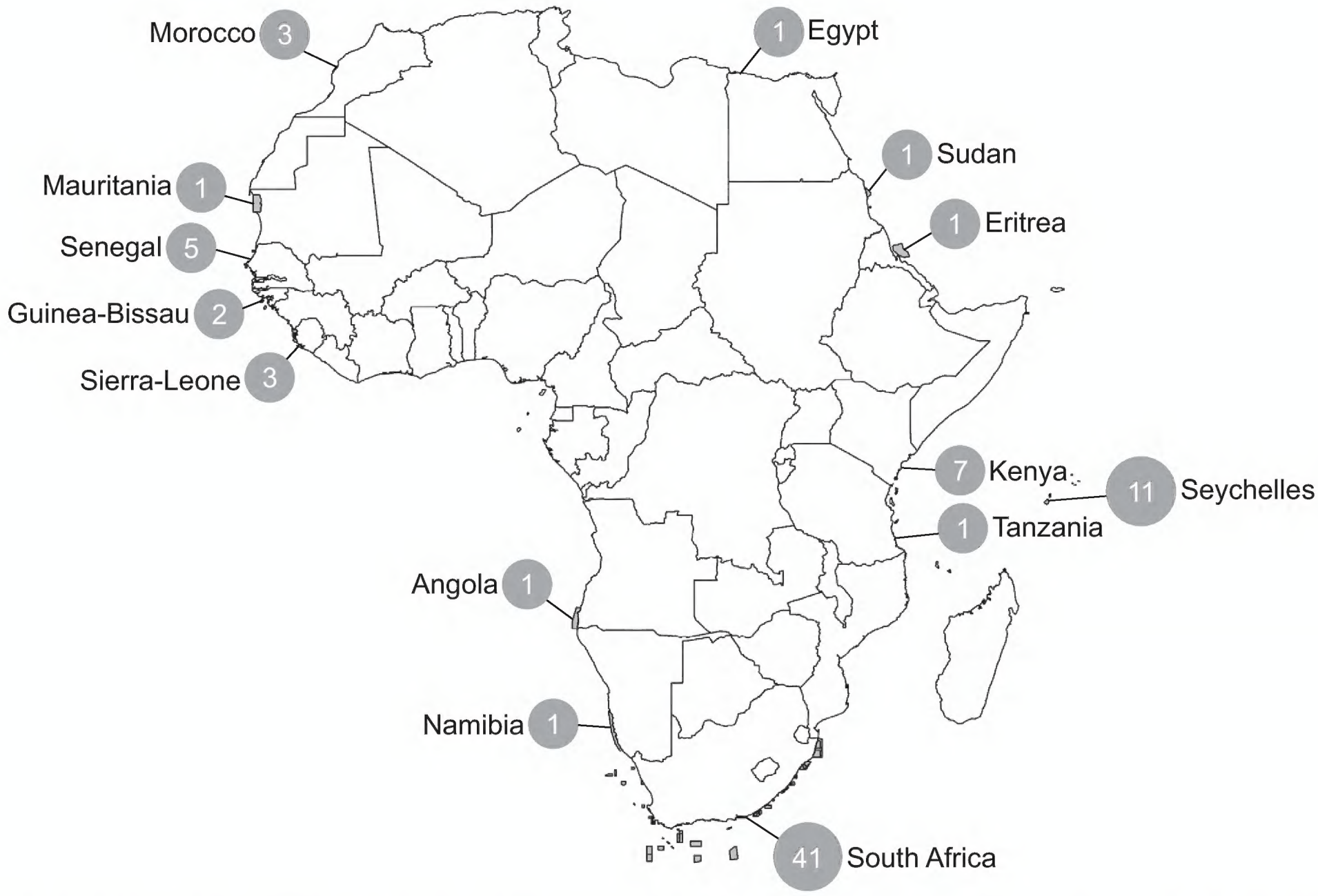

Figure 1. Location of the 14 African countries and the number of marine protected areas declared within those countries on the Protected Planet database.

material 2: table S5) and four species were listed as data deficient. Namibian Islands (Namibia) and Langebaan Lagoon (South Africa) were the only MPAs that supported species with massive (i.e. the oyster *Magallana gigas* and the Mediterranean mussel *Mytilus galloprovincialis*) and major impact (i.e. the mussel *Semimytilus patagonicus*, the ascidian *Ciona robusta* and the bryozoan *Amathia verticillata*). Table Mountain National Park MPA in South Africa had the highest number of species with previously documented impacts. This MPA had a single species known for massive impact (i.e. the Mediterranean mussel *Mytilus galloprovincialis*) and three species for which major impact had been reported (i.e. the European green crab *Carcinus maenas*, the mussel *Semimytilus patagonicus* and the ascidian *Ciona robusta*). Banc d'Arguin National Park in Mauritania had the second highest number of species with previously documented impacts. While some species displayed only environmental mechanisms of impact, a general pattern was that species that exerted environmental impact through multiple mechanisms also had many mechanisms of socio-economic impact and ultimately exerted high impacts (Pearson's product-moment correlation: $r = 0.79$, $p < 0.001$; Fig. 5, Suppl. material 2: table S5). Three species had a high number of environmental and socio-economic mechanisms of impact (i.e. the oyster *Magallana gigas* and the mussels *Mytilus galloprovincialis* and *Semimytilus patagonicus*). The Pacific oyster, *Magallana gigas*, had the highest number of mechanisms through which it has caused environmental and socio-economic impacts. This species was only observed within Namibian Islands MPA in Namibia.

Table 1. The species detected on iNaturalist within African marine protected areas and the magnitude of their environmental impact (as per Blackburn et al. 2014) and socio-economic impact (as per Bacher et al. 2017). Marine protected area codes are as follows: iSimangaliso (iSi); Aliwal (Ali); Protea Banks (Pro); Amathole (Ama); Addo Elephant (Add); Betty's Bay (Bet); Table Mountain National Park Marine Protected Area (Tmn); Robben Island (Rob); Sixteen Mile Beach (Smb); Langebaan Lagoon (Lan); Namaqua National Park (Nam); Namibian Islands (Nim); Namibe Marine (Nmc); Ihas Formosa, Nago & Tchedia (Iha); Gorée (Gor); Banc d'Arguin National Park (Ban) and Massa (Mas). Numbers (#) assigned to species correspond to the numbers in Figs 4, 5.

#	Scientific name	Country	Marine protected area	Environmental impact	Socio-economic impact	Impact literature
1	*Ectopleura crocea*	South Africa	Tmn	Moderate	Minor	Fitridge and Keough 2013; Yan et al. 2021
2	*Obelia dichotoma*	South Africa	Tmn	Moderate	Data deficient	Wyatt et al. 2005
3	*Tridentata marginata*	Mauritania	Ban	Data deficient	Data deficient	
4	*Anisolabis maritima*	South Africa	Tmn	Data deficient	Data deficient	
5	*Amphibalanus venustus*	South Africa	Ali; Ama	Data deficient	Data deficient	
6	*Balanus glandula*	South Africa	Ali; Tmn	Moderate	Data deficient	Kado 2003; Vallarino and Elias 2008
7	*Balanus trigonus*	Angola	Nmc	Minimal	Minimal	Lozano-Cortès and Zapata 2014; Abelouah et al. 2024
		Mauritania	Ban			
8	*Megabalanus tintinnabulum*	South Africa	iSi, Tmn	Moderate	Data deficient	Pfaff et al. 2022
9	*Callinectes sapidus*	Guinea-Bissau	Iha	Major	Minor	Clavero et al. 2022; Mancinelli et al. 2017
		Mauritania	Ban			
		Morocco	Mas			
10	*Carcinus maenas*	South Africa	Tmn	Major	Minor	Grosholz et al. 2011; Breen and Metaxas 2008 Whitlow 2010; de Rivera et al. 2011; Mabin et al. 2022
11	*Amathia verticillata*	Mauritania	Ban	Major	Minor	McCann et al. 2015
		South Africa	Lan			
12	*Bugula neritina*	South Africa	Bet	Minor	Minor	Yu et al. 2007; Bae et al. 2022
13	*Virididentula dentata*	South Africa	iSi; Tmn	Minimal	Data deficient	Micael et al. 2016
14	*Watersipora subtorquata*	South Africa	Add; Tmn	Minor	Minor	Sellheim et al. 2010; McKenzie et al. 2011
15	*Magallana gigas*	Namibia	Nam	Massive	Major	Troost 2010; Kelly et al. 2008
16	*Mytilus galloprovincialis*	Mauritania	Ban	Massive	Major	Branch and Steffani 2004; Steffani and Branch 2005; Alexander et al. 2015
		Namibia	Nim			
		South Africa	Lan; Nam; Rob; Smb; Tmn			
17	*Semimytilus patagonicus*	Namibia	Nam	Major	Major	Skein et al. 2018
		South Africa	Lan; Tmn			
18	*Siphonaria pectinata*	Mauritania	Ban	Minor	Data deficient	Boukhicha et al. 2015
19	*Thecacera pennigera*	South Africa	Tmn	Data deficient	Data deficient	
20	*Ophiactis savignyi*	Guinea-Bissau	Iha	Minor	Data deficient	Çinar et al. 2019
		South Africa	Pro			
21	*Botryllus schlosseri*	South Africa	Tmn	Moderate	Data deficient	Wong and Vercaemer 2012
22	*Ciona robusta*	South Africa	Lan; Tmn	Major	Minor	Robinson et al. 2017
23	*Clavelina lepadiformis*	South Africa	Tmn	Minimal	Data deficient	Casso et al. 2018
24	*Diplosoma listerianum*	South Africa	Tmn	Minor	Minimal	Aldred and Clare 2014
25	*Symplegma brakenhielmi*	Senegal	Gor	Minor	Minimal	Spyksma et al. 2024
26	*Acanthophora spicifera*	Mauritania	Ban	Moderate	Data deficient	Davidson et al. 2015
27	*Hypnea musciformis*	Guinea-Bissau	Iha	Moderate	Minimal	Okuhata et al. 2023
		Mauritania	Ban			
		Senegal	Gor			

Discussion

Invasive species are major drivers of global change (Pyšek et al. 2020) and invasions directly undermine the conservation objectives of protected areas (Ren et al. 2021). It is, therefore, critical to identify the protected areas that are most at risk to invasions and the species that may pose the greatest threat to them (Pyšek et al. 2020). However, the current lack of baseline data on alien species in MPAs hinders this task, since information on the scale of invasions in MPAs is lacking in most

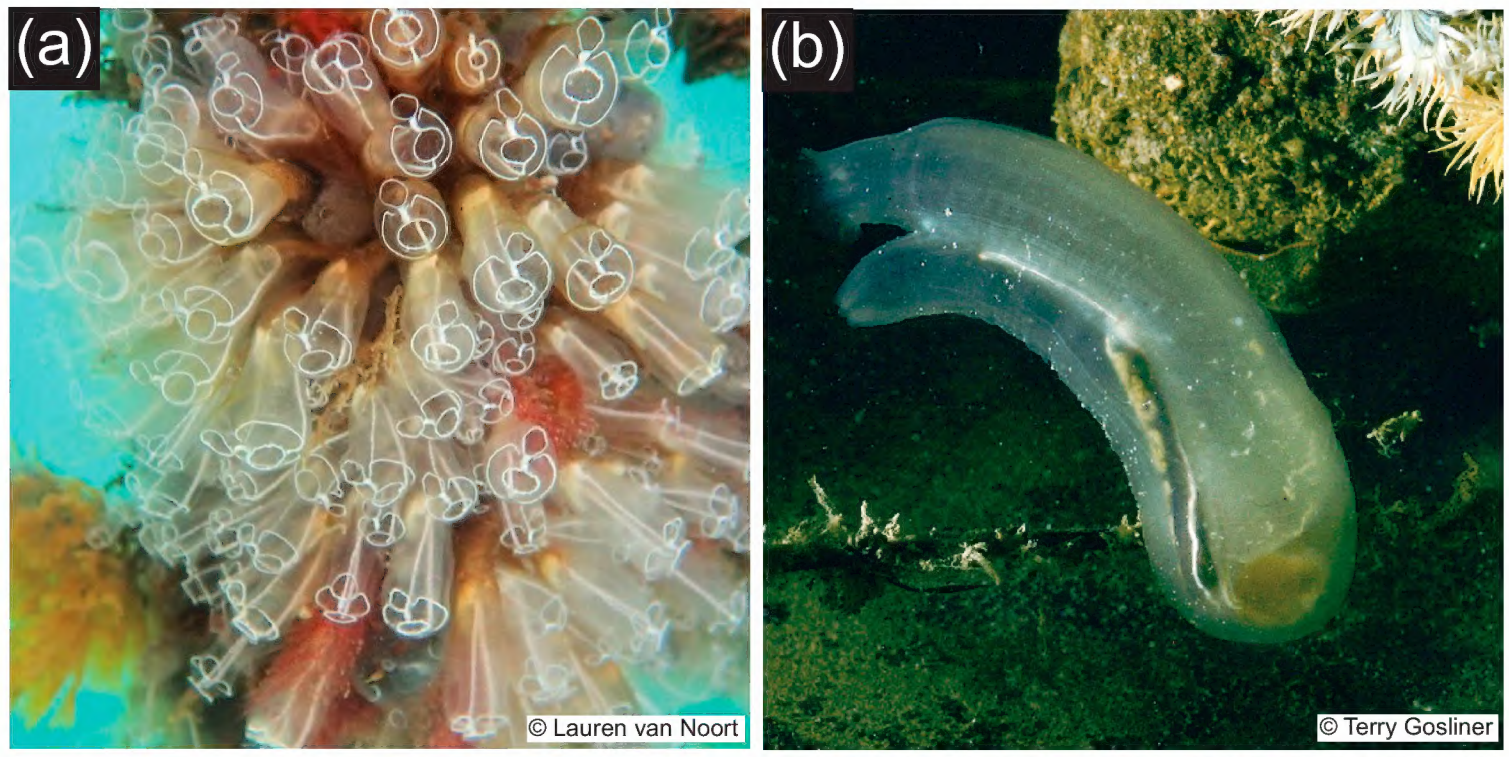

Figure 2. iNaturalist records that contributed towards the findings of this study. **a.** *Clavelina lepadiformis* (iNaturalist ID 152956163); **b.** *Ciona robusta* (iNaturalist ID 69033891); **c.** *Thecacera pennigera* (iNaturalist ID 23247918); **d.** *Callinectes sapidus* (iNaturalist ID 174999050).

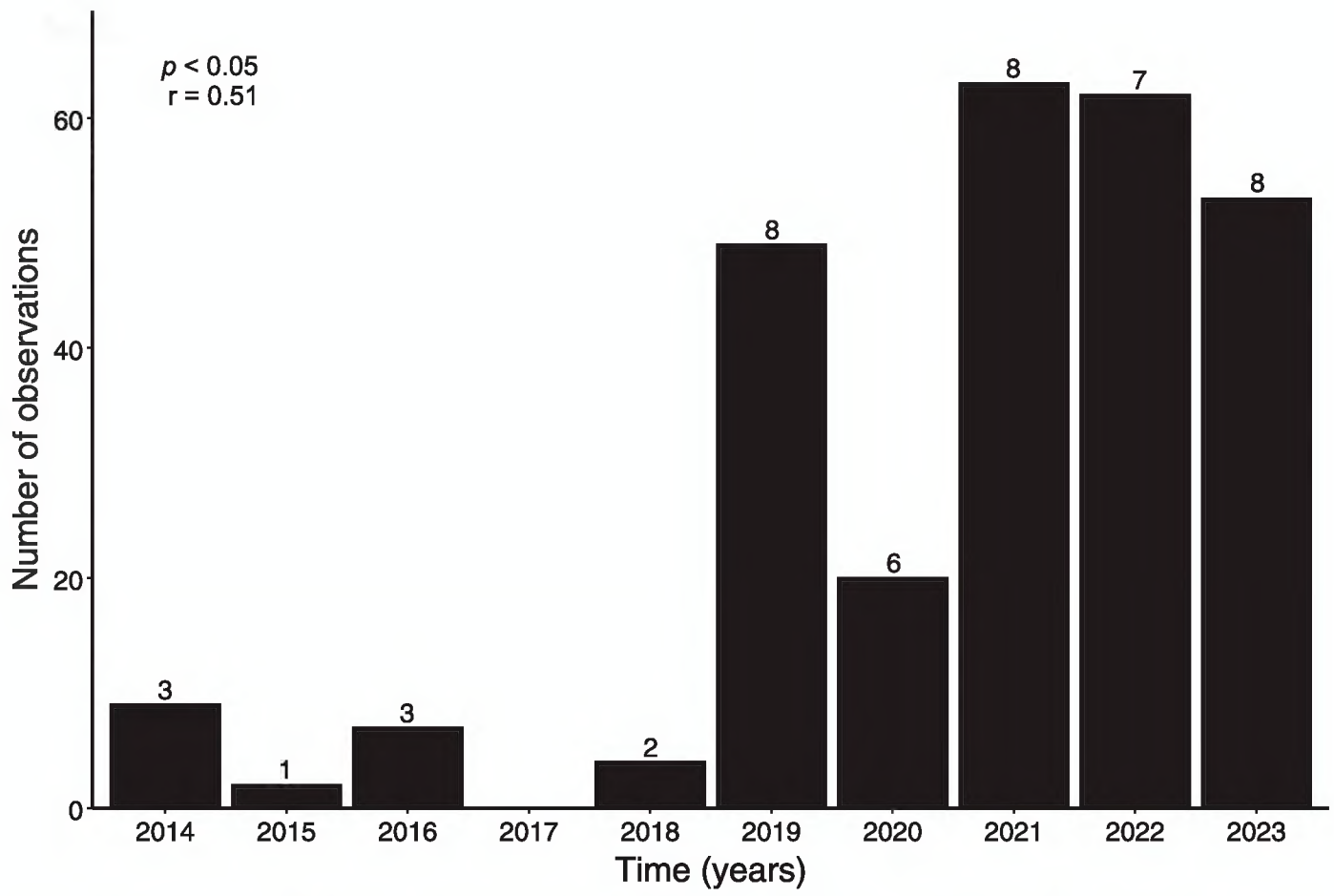

Figure 3. The number of alien species with records on iNaturalist in African marine protected areas (MPAs) over time. Numbers above bars indicate the number of alien species records per 100 records within African MPAs.

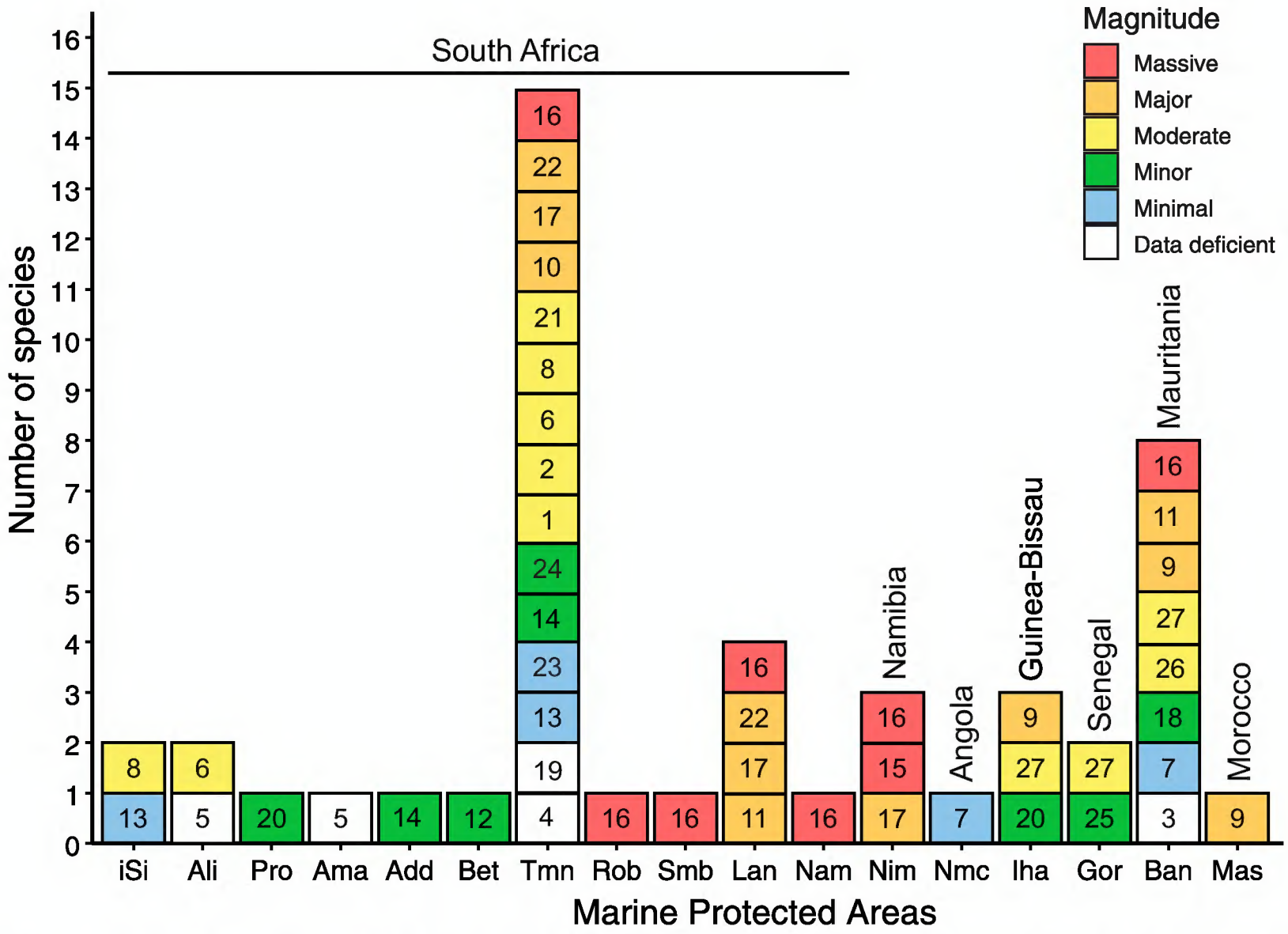

Figure 4. The number of marine alien species with records in iNaturalist across marine protected areas (MPAs) and the countries in which they occurred. Species are categorised according to the highest magnitude of impact noted for the species. Species codes (numbers in the boxes) are explained in Table 1. MPA names (below x axis): iSimangaliso (iSi); Aliwal (Ali); Protea Banks (Pro); Amathole (Ama); Addo Elephant (Add); Betty's Bay (Bet); Table Mountain National Park Marine Protected Area (Tmn); Robben Island (Rob); Sixteen Mile Beach (Smb); Langebaan Lagoon (Lan); Namaqua National Park (Nam); Namibian Islands (Nim); Namibe Marine (Nmc); Ihas Formosa, Nago & Tchedia (Iha); Gorée (Gor); Banc d'Arguin National Park (Ban) and Massa (Mas).

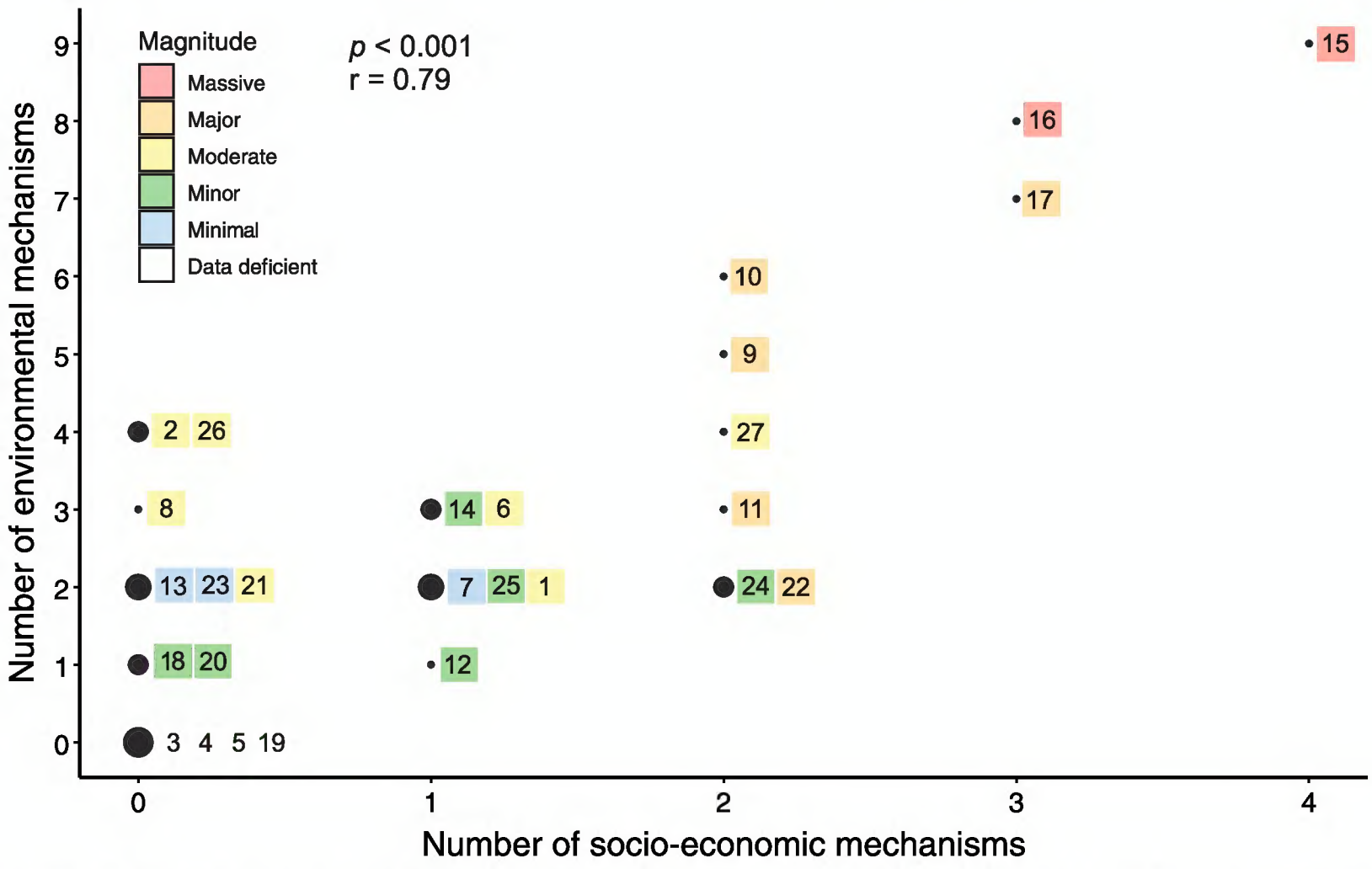

Figure 5. The relationship between the environmental and socio-economic mechanisms reported for each species recorded within an African marine protected area. The magnitude of impact for each species is indicated by the colours; the size of the points represents the number of species. The numbers alongside points indicate species as listed in Table 1.

regions. In response to this need, this study drew together existing information to advance our current understanding on the scale of invasions in African MPAs. Four species [the barnacle *Balanus trigonus* (Mauritania), the bryozoan *Amathia verticillata* (Mauritania and South Africa), the colonial tunicate *Symplegma brakenhielmi* (Senegal) and the crab *Callinectes sapidus* (Guinea-Bissau and Mauritania)] were documented in countries for which there were no previous records in WRiMS or in literature. Impacts were identified for all, except four species documented in this study. Two of these species (the bivalves *Mytilus galloprovincialis* and *Magallana gigas*) are known to have massive impact within invaded regions across globe.

Marine protected areas serve diverse ecological and socio-economic goals that aim to protect biodiversity and secure the ecosystem services that flow from intact systems (Sala et al. 2018; Rees et al. 2018; Giakoumi et al. 2019). This alignment with the GBF targets highlights that MPAs are important for achieving these targets. In this study, records of alien taxa were detected within 17 MPAs across seven African countries. The detection of four species in countries from which they have not previously been reported adds valuable information on alien marine species within these regions. However, it is vital for MPA managers to conduct field surveys to ground-truth these records and to determine whether these species are indeed established to provide information for possible management responses. Table Mountain National Park Marine Protected Area (TMNP MPA) in South Africa had the highest number of records and the highest number of alien species of all MPAs. There are several possible reasons for the high level of citizen science engagement in this MPA. Firstly, TMNP MPA is located within the popular tourist city of Cape Town. It is also home to a number of natural attractions, including a breeding colony of African penguins (*Spheniscus demersus*) which received about 800,000 visitors in 2019 (Kock et al. 2022). Secondly, access to most of TMNP MPA is unrestricted, enabling easy access to both locals and visitors. Furthermore, good internet coverage across the MPA facilitates engagement on the iNaturalist platform. Another way in which the uptake of records on to iNaturalist has been accelerated in this MPA is through participation in the 'City Nature Challenge' (https://www.inaturalist.org/projects/city-nature-challenge-2024-city-of-cape-town). This is a global citizen science event that aims to document biodiversity within cities over a designated period. This event is widely advertised within Cape Town, which has a large community of marine users (e.g. SCUBA divers and free-divers). Banc d'Arguin National Park in Mauritania had the second highest number of records and detections of alien species. Unlike the high community engagement with the TMNP MPA, the large number of iNaturalist records from Banc d'Arguin National Park were contributed by a small number of individuals; a single person contributed hundreds of records within this MPA in a single year. The contrasting nature of the iNaturalist users in these two MPAs highlights the importance of a strong community of observers and tourists, but also the role that 'champion' individuals have in driving use of the platform (Howard et al. 2022).

Impacts have only been studied for a small proportion of known marine alien species (Watkins et al. 2021). This is evident in large research biases towards particular invaders and the potential and actual impacts for numerous marine alien species remain unknown (Ojaveer et al. 2015; Watkins et al. 2021). In addition, complex or indirect impacts are difficult to detect (Davidson and Hewitt 2014) and there may also be a delay in the manifestation of impact due to lags in the invasion process (Crooks 2005; Iacarella et al. 2015). Nonetheless, some information

on impact was available for all, but four species detected in this study. The magnitude of these reported impacts ranged from minimal to massive. Three bivalves (i.e. the Pacific oyster, *M. gigas* and the mussels, *M. galloprovincialis* and *Semimytilus patagonicus*) had the highest number of mechanisms of environmental and socio-economic impact and were classified as having either massive or major impact, highlighting the threat that they may pose within MPAs. Oysters and mussels are commercially important bivalves (Wijsman et al. 2019) and are imported for mariculture all around the world. Escapes from mariculture farms pose a biosecurity risk (Harikrishnan et al. 2024) with impacts including biofouling (Lins et al. 2021; Parisi et al. 2022), habitat alteration (Linares et al. 2022), hybridisation (Brannock and Hilbish 2010), competition with native species (Oyarzún et al. 2024) and losses in material and immaterial assets (Veiga et al. 2020). As a result, escapes can result in irreversible impacts on aquatic ecosystems (Thorvaldsen et al. 2015; Kang et al. 2022). Therefore, the identification of high-impact species, such as these bivalves in MPAs, is important as managers are then able to prioritise the allocation of resources and make strategic decisions on how to address such introductions. Prevention is the most cost-effective way to manage marine invasions (Ojaveer et al. 2015; Tsiamis et al. 2020; Simberloff 2021). Therefore, as nations expand MPA networks in response to GBF Target 3, spatial planning must address the link between invasions and mariculture (Hulme et al. 2025).

The high levels of engagement with iNaturalist in the TMNP MPA and the resulting high number of detections of alien species highlights the need to increase participation on this platform in other MPAs, if the full value of the platform is to be realised. There are a number of ways in which the use of iNaturalist can be encouraged. Events such as iNaturalist "BioBlitzes" are very useful; these aim to assess the biodiversity present within a specific geographic area over a short period of time (Meeus et al. 2023). They have engaged a large number of people worldwide in gathering and sharing information on biodiversity in both natural and urban areas (Postles and Bartlett 2018). Such events have played important roles in monitoring alien species by providing up-to-date, accurate and complete occurrence data. For example, the Texas Invasive Species BioBlitz was used to reassess previously invaded sites for alien plant species (Meeus et al. 2023). The engagement of the public and coordinated knowledge sharing is critical to boosting iNaturalist use. For example, iNaturalist has been successfully integrated into school-based initiatives (Echeverria et al. 2021) which promotes the importance of collecting biodiversity data amongst the youth.

Despite the utility of the method used in this study, limitations associated with global databases must be noted. Firstly, some species are not conducive to this form of supplemental monitoring as they are too small to record on images by amateur observers (e.g. microscopic dinoflagellates and protists) (Ackland et al. 2024). The general lack of interest in non-charismatic species (see Munzi et al. (2023)) also affects their representation in non-specialist surveys. Furthermore, although WRiMS is the most comprehensive global database currently available (Costello et al. 2021), it is a work in progress and requires continual updating. The fact that this study found no additional records during a thorough literature search shows that the database accurately reflects the current state of knowledge, at least for some regions. However, it is recommended that, where possible, management agencies should supplement these data with multifaceted studies that develop comprehensive alien species lists (Carlton and Schwindt 2024) and insights from locals and stakeholders to capture indigenous knowledge (Azzurro et al. 2019; Henke et

al. 2025). Nonetheless, the methodology proposed in this paper provides a strong foundation upon which traditional survey methods can build. The method used in this study would be most beneficial for countries that are starting to create inventories of alien species [e.g. Algeria (Grimes et al. 2018) and Morocco (Mghili et al. 2024)]. In a broader context, the method proposed in this study could also be implemented to monitor areas surrounding suspected points of introduction (e.g. commercial harbours and ports) and buffer zones around protected areas to identify species that may not yet have reached the area of concern.

Conclusions

Through the use of global databases and citizen science data from iNaturalist, this study provided novel insights on the presence of alien species in African MPAs in a cost-effective manner. The study also assessed the environmental and socio-economic impacts associated with taxa recorded in these MPAs. Together, these insights provide information that is critical for management agencies to make strategic decisions about introductions in these understudied areas of conservation importance. Moreover, these data advances regional knowledge of marine invasions and provide a foundation upon which States can begin to build their response to GBF target 6.

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Additional information

Conflict of interest

The authors have declared that no competing interests exist.

Ethical statement

No ethical statement was reported.

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Author contributions

All authors conceptualised the paper. SJA undertook the data analyses. All authors contributed to the written manuscript and approved the submission thereof.

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Data availability

The dataset and the description thereof will be available from Zenodo (https://doi.org/10.5281/zenodo.14840792). All other associated data are provided in the Supplementary Information.

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Supplementary material 1

Filters used to identify marine protected areas along the coast of Africa on the Protected Planet database

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Data type: docx

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Supplementary material 2

Supplementary information

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Data type: xlsx

Explanation note: **table S2.** Marine protected areas identified from the Protected Planet database and the countries in which they have been declared. **table S3.** Marine alien species as identified on WRiMs and the countries in which they have been reported. **table S4.** Species reported within African marine protected areas on iNaturalist. **table S5.** The assessment of the magnitude of impact of species according to the EICAT (Blackburn et al. 2014) and SEICAT (Bacher et al. 2017) schemes.

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